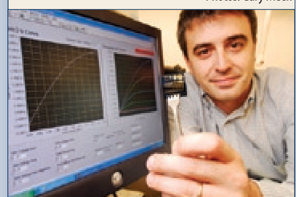
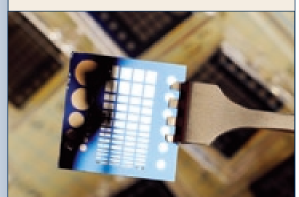
Researchers have used room-temperature processes to fabricate high-performance field-effect transistors with thin films of carbon 60. The work represents an advance toward large-area, low-cost electronic circuits on flexible organic substrates.

Photos: Gary Meek





Researcher Benoit Domercq (above) shows a sample of high-performance carbon 60 transistors. Lower image shows a close-up of the sample.

"If you open a textbook and look at what a thin-film transistor should do, we are pretty close now."

- Bernard Kippelen, professor in the School of Electrical and Computer Engineering

Organic Transistors:

Researchers Produce High-Performance Field-Effect Transistors with Thin Films of Carbon 60

By John Toon

Using room-temperature processing, Georgia Tech researchers have fabricated high-performance field-effect transistors with thin films of carbon 60 (C_{60}), also known as fullerene. The ability to produce devices with such performance with an organic semiconductor represents another step toward practical applications for large-area, low-cost electronic circuits on flexible organic substrates.

The new devices – which have electron-mobility values higher than amorphous silicon, low threshold voltages, large on-off ratios and high operational stability – could encourage more designers to begin working on such circuitry for displays, active electronic billboards, RFID tags and other applications that use flexible substrates.

"If you open a textbook and look at what a thin-film transistor should do, we are pretty close now," says Bernard Kippelen, a professor in Georgia Tech's School of Electrical and Computer Engineering and the Center for Organic Photonics and Electronics. "Now that we have shown very nice single transistors, we want to demonstrate functional devices that are combinations of multiple components. We have everything ready to do that."

Fabrication of the C_{60} transistors was reported in the journal *Applied Physics Letters* [Vol. 91, 092114 (2007)]. The research was supported by the U.S. National Science Foundation through the STC program MDITR, and the U.S. Office of Naval Research.

Researchers have been interested in making field-effect transistors and other devices from organic semiconductors that can be processed onto various substrates, including flexible plastic materials. As an organic semiconductor material, C_{60} is attractive because it can provide high electron mobility – a measure of how fast current can flow. Previous reports have shown that C_{60} can yield mobility values as high as six square centimeters per volt-second (6 $cm^2/V/s$). However, that record was achieved using a hot-wall epitaxy process requiring processing temperatures of 250 degrees Celsius – too hot for most flexible plastic substrates.

Though the transistors produced by Kippelen's research team display slightly lower electron mobility – 2.7 to 5 $cm^2/V/s$ – they can be produced at room temperature.

"If you want to deposit transistors on a plastic substrate, you really can't have any process at a temperature of more than 150 degrees Celsius," Kippelen adds. "With room temperature deposition, you can be compatible with many different substrates. For low-cost, large area electronics, that is an essential component."

Because they are sensitive to contact with oxygen, the C_{60} transistors must operate under a nitrogen atmosphere. Kippelen expects to address that limitation by using other fullerene molecules – and properly packaging the devices.

The new transistors were fabricated on silicon for convenience. While Kippelen isn't underestimating the potential difficulty of moving to an organic substrate, he says that challenge can be overcome.

Though their performance is impressive, the C_{60} transistors won't threaten conventional CMOS chips based on silicon. That's because the applications Kippelen has in mind don't require high performance.

"There are a lot of applications where you don't necessarily need millions of fast transistors," he says. "The performance we need is by far much lower than what you can get in a CMOS chip. But whereas CMOS is extremely powerful and can be relatively low in cost because you can make a lot of circuits on a wafer, for large-area applications CMOS is not economical."

A different set of goals drives electronic components for use with low-cost organic displays, active billboards and similar applications.

"If you look at a video display, which has a refresh rate of 60 Hz, that means you have to refresh the screen every 16 milliseconds," he notes. "That is a fairly low speed compared to a Pentium processor in your computer. There is no point in trying to use organic materials for high-speed processing because silicon is already very advanced and has much higher carrier mobility."

Now that they have demonstrated attractive field-effect C_{60} transistors, Kippelen and collaborators Xiao-Hong Zhang and Benoit Domercq plan to produce other electronic components such as inverters, ring oscillators, logic gates, and drivers for active matrix displays and imaging devices. Assembling these more complex systems will showcase the advantages of the C_{60} devices.

The researchers fabricated the transistors by depositing C_{60} molecules from the vapor phase into a thin film atop a silicon substrate onto which a gate electrode and gate dielectric had already been fabricated. The source and drain electrodes were then deposited on top of the C_{60} films through a shadow mask.

Kippelen's team has been working with C_{60} for nearly 10 years, and is also using the material in photovoltaic cells. Beyond the technical advance, Kippelen believes this new work demonstrates the growing maturity of organic electronics. rh

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Photo: Gary Meek

Researcher Xiao-Hong Zhang examines carbon 60 transistors in a glove box in the laboratory of Bernard Kippelen.